92-1070

A92-33242

AIAA 92-1070
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1992 Aerospace Design Conference
February 3-6, 1992 /Irvine, CA

U4265

Accession Number: 4265

Publication Date: Feb 03, 1992

Title: Lightweight Exo-Atmospheric Projectile (LEAP) Space Test--LEAP 2 Flight

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Corporate Author Or Publisher: USASDC, Huntsville, AL; Hughes Aircraft Co., Missile Systems, Canoga P Report Number: AIAA 92-1070

Comments on Document: 1992 Aerospace Design Conference, Irvine, CA

Descriptors, Keywords: LEAP 2 Space Flight Test Flight AIAA Projectile Launch Critical Technology

Pages: 00005

Cataloged Date: Jan 27, 1993

Document Type: HC

Number of Copies In Library: 000001

Record ID: 26091

Source of Document: AIAA

AIAA-92-1070

LIGHTWEIGHT EXO-ATMOSPHERIC PROJECTILE (LEAP) SPACE TEST LEAP 2 FLIGHT

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Abstract

The Army Lightweight Exo-Atmospheric Projectile (LEAP) will demonstrate hit to kill intercept performance against a non-boosting target during the Strategic Defense Initiative Organization's LEAP 2 space test at White Sands Missile Range early in 1992. The Army LEAP is the lightest weight interceptor currently developed. The LEAP 2 mission will fully validate the performance of this interceptor in a space environment. Data from the LEAP 2 mission will be used to complete validation of projectile simulation models. LEAP 2 has a high probability of success based on analysis and test data. Information gained from LEAP 2 will be used to ensure a high probability of success for future, even more stressing, space tests.

I. Overview

The Strategic Defense Initiative Organization (SDIO) has developed various lightweight interceptor technology components, many of which are now integrated into projectiles. Ground based testing, including hover tests performed at the National Hover Test Facility located at Edwards Air Force Base in California, have been used to demonstrate these technologies. The SDIO is constructing a sequence of space tests which will further demonstrate the technology components which have been integrated into these interceptors. LEAP 2 is the designation for the first space test which will verify the performance of the fully integrated interceptor developed by the Army.

The Army Lightweight Exo-Atmospheric Projectile is the smallest of the SDIO developed interceptors, weighing just 6 kilograms. The LEAP 2 mission scenario is constructed to demonstrate all subsystems of the projectile, including the critical technology developments. In the LEAP 2 space test the projectile autonomously tracks and diverts to intercept a non-boosting target. The target uses a solid motor to provide the axial closing velocity of 840 meters/second. Another space test at White Sands Missile Range will again demonstrate the Army LEAP projectile performance against a non-boosting target at a higher closing velocity of 2.5 kilometers/second. The second space test (LEAP 4) will occur at White Sands Missile Range in late 1992. Additional space tests with increasing closing velocities and various encounter scenarios are planned to occur in 1992 and 1993 at Kwajelein Missile Range. This paper addresses the LEAP 2 mission only.

The Army LEAP Program is managed for the SDIO by the U.S. Army Strategic Defense Command in Huntsville, Alabama. Contract administration and technical direction is provided by the U.S. Army Armaments Research, Development and Engineering Center in Dover, New Jersey. The prime contractor for the Army LEAP is Hughes Aircraft Company, Missile Systems Group in Canoga Park, California. The Marquardt Company, Van Nuys, California is subcontractor for the propulsion system.

II. Projectile Critical Technology Developments

The Army LEAP incorporates several critical technology components into the lightest weight currently integrated projectile. The objective of the LEAP 2 space test is to demonstrate all of these integrated technology components in a space intercept of a target similar to a reentry vehicle. Figure 1 is a picture of the Army LEAP projectile. The projectile critical technology components are described in the following paragraphs.

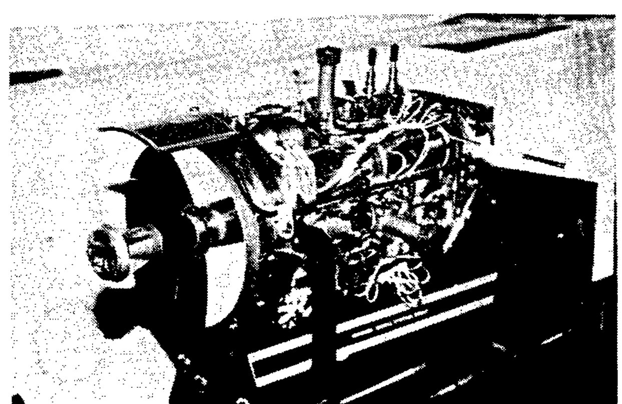

Figure 1. Army Lightweight Exo-Atmospheric Projectile

The Electronics Unit, which provides processing of image data, guidance and control and input/output functions has been miniaturized specifically for the Army LEAP Program using Wafer Scale Integration techniques. Noise immunity and weight minimization are the primary assets of the Wafer Scale Integration design and assembly method, which results in a 10:1 reduction in board area when compared to standard printed circuit board technology. This Hughes proprietary method is used in assembling eight daughterboards onto one doublesided motherboard. Wafer Scale Integration involves bonding bare integrated circuit die onto the polyimide/alumina daughterboards which are then wirebonded onto the motherboard. The entire Electronics Unit weighs just 140 grams (5 ounces). The compactly packaged Electronics Unit is capable of withstanding rocket booster launch environments as well as disturbances induced by the projectile's own divert and attitude control thruster firings.

Another critical technology component is the Medium Wave Infrared (MWIR) Seeker which includes a Focal Plane Array (FPA) cryogenically cooled in a lightweight dewar assembly and an optics assembly. The staring FPA is a 128 by 128 Mercury/Cadmium/Telluride (HgCdTe) array of 40 micrometer by 40 micrometer unit cells. A key characteristic of the Sensor is its enhanced sensitivity (<20 fW/cm^2). The optics assembly has a 14 centimeter (5.5 in.) diameter aperture. Primary and secondary mirrors are constructed of Beryllium to minimize weight. Refractive optics elements are silicon and germanium. The total field of view is 1.1 degree by 1.1 degree. The waveband for the first space flight is 3-5 micrometers. The current MWIR Seeker is adaptable to Long Wave Infrared (LWIR). Future space flights will utilize a 7-9 micrometer waveband. The primary mirror forms part of the casing which encloses the Electronics Unit. The entire Guidance Unit (IR Seeker and Electronics Unit) weight is only 864 grams (1.9 pounds).

A significant technological advancement developed for the Army LEAP is the lightest weight, fully integrated propulsion system ever built. The miniaturized hypergolic propulsion system weighs just 3640 grams fully fueled, including 400 grams each of Hydrazine (N_2H_4) and Nitrogen Tetroxide (N_2O_4). Four lateral divert engines each provide 160 Newtons (36 pounds) of thrust. More than 500 meters/second (1640 feet/second) of divert is available. Eight 4.5 Newton (1 pound) attitude control thrusters maintain the target within 3 milliradians of the seeker boresight during the divert. Divert thruster response time is 5 milliseconds and the minimum impulse bit is 1.8 Newton-seconds (0.4 pound-second). The attitude control thruster response time is less than 1 millisecond and the minimum impulse bit is 0.009 Newton-second (0.002 pound-second). The propulsion system is designed to prevent drift of the projectile center of mass during the intercept. Helium pressure is used to move pistons, expelling propellant from two fuel and two oxidizer tanks. The tanks are symmetrically located about the projectile longitudinal axis. The pistons in the two sets of tanks (fuel and oxidizer) are positioned at opposite ends of the tanks and move toward each other as propellant is used. Sequencing the selection of propellant tanks for each thruster firing ensures uniform expulsion from each tank. The center of mass is maintained within one millimeter radially and within two millimeters axially.

Tracking and guidance software algorithms are also critical LEAP technologies. The tracking system evaluates image data from the seeker to determine target position in the field of view. The closed loop guidance system subtracts the projectile body rates from the apparent target motion and derives the actual target motion. A new target centroid position is predicted by the Kalman guidance filter every 60 Hertz frame and the track gate is positioned about the predicted target location. A track gate size of 5 pixels by 5 pixels is selected for unresolved targets. The track gate size grows as the target enlarges in the field of view during the closing encounter. Maintaining alignment of the body fixed seeker to the inertial sensor assembly is critical for closed loop guidance during the divert maneuver. The vehicle structure fundamental bending frequency of 1500 Hertz ensures less than 60 microradians (peak to peak) alignment shift during divert.

In addition to the specially developed technologies discussed above, the space test will demonstrate the performance of the other projectile subsystems. The lightweight Inertial Sensor Assembly (ISA) provides three axis rate gyro and accelerometer outputs. The lithium alloy/iron disulfide thermal battery weighs just 240 grams and provides more than one watt hour of power. The 250 gram (9 ounce) RF telemetry subsystem transmits 11.2 mega-bits-per-second (MBPS) of telemetry data, including infrared video, performance and housekeeping data.

III. LEAP 2 Space Test Scenario

The LEAP 2 space test is designed to fully demonstrate the Army LEAP integrated technology components by performing a free flight space intercept of a target similar to a reenty vehicle. The space test trajectory is illustrated in Figure 2. Times and distances shown are approximate. White Sands Missile Range, New Mexico has been chosen as the location of this flight.

Mission Overview

The launch vehicle chosen for this flight is a Minuteman I (MMI), Stage II (M56) solid rocket booster. A Payload Module Bus (PMB) provides guidance during the boost phase and serves as a stable platform from which to launch the projectile prior to the target intercept. The target is launched from the same booster as the LEAP. The target is pneumatically separated after the rocket motor boost phase and uses cold nitrogen gas expulsion to achieve a distance of about 20 kilometers from the Payload Module Bus. A modified Viper solid motor is ignited on the target to provide an approximate closing velocity of one kilometer per second.

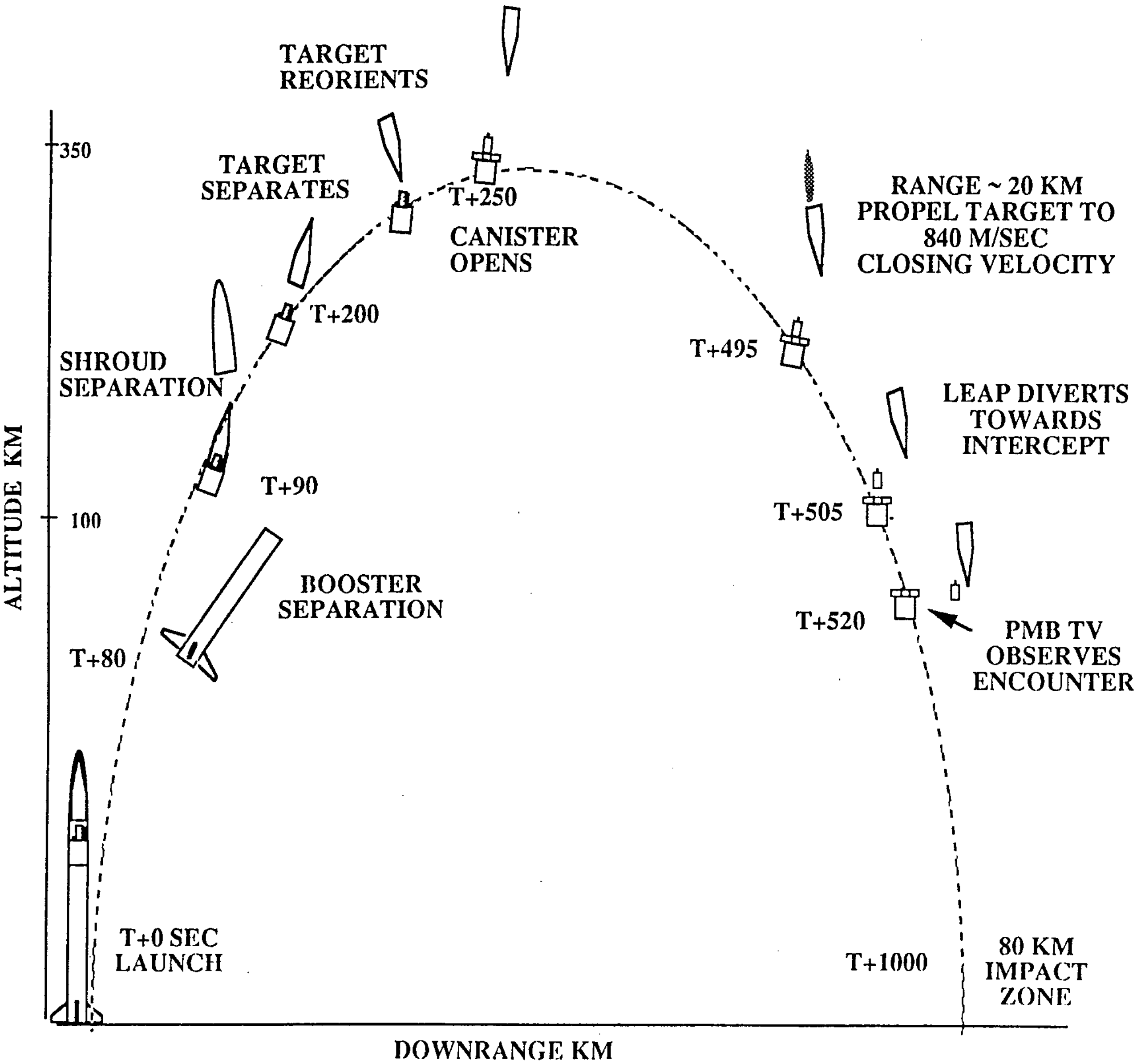

Figure 2. LEAP 2 Trajectory Illustration

The LEAP 2 space test achieves the objectives of demonstrating the fully integrated projectile within the range safety constraints of White Sands Missile Range. The projectile operates autonomously of the Payload Module Bus, receiving only power and initialization commands. The projectile locks onto the target prior to ejection from the Payload Module Bus, receives Kalman guidance filter initialization information on the target velocity and position, then autonomously tracks and diverts to intercept the target. The projectile receives no update corrections on target velocity or position during free flight, and is capable of steering out errors in the initial target information as it diverts up to one kilometer for the intercept.

Projectile Support Hardware

Projectile support hardware includes a Canister, Cryogen Storage System and an Electrical Interface Unit. The Canister provides environmental protection and a precision machined ejection platform which will induce minimal disturbance as the projectile is ejected. The Cryogen Storage System provides 30 minutes of Argon gas for FPA cooling after booster launch. The projectile FPA is cooled from its 30 second Argon supply during free flight. The Electrical Interface Unit conditions +28V battery power from the Payload Module Bus into the regulated power forms required by the LEAP. The Electrical Interface Unit also buffers discrete commands and conditions serial interface data to the projectile from the Payload Module Bus.

Prelaunch Events

Propellants are loaded into the projectile and final weight and center of gravity adjustments are made a few days before assembly onto the booster on the launch pad. Just prior to assembly on the launch pad the PMB tracker is electrically aligned to the projectile seeker and FPA nonuniformity gain terms and other projectile software initialization parameters are loaded into the projectile computer storage.

About eight hours prior to booster launch, the projectile helium tanks are pressurized. Ground supplied Argon is routed through a PMB quick disconnect fitting to cool the projectile FPA. (This quick disconnect separates at booster launch.) A few hours prior to launch the projectile is powered up to verify launch readiness. The canister squibs are checked and armed as part of the final booster arming procedure one hour before launch. Also at this time the projectile helium fill line and vacuum pump are disconnected at the canister wall. Five minutes prior to launch the FPA cooling is switched from ground supplied Argon to the PMB supply and the LEAP is powered up for a final launch readiness verification. The Electrical Interface Unit power remains on at this time to obtain its telemetry information via the PMB telemetry data during launch.

LEAP 2 Space Test Timeline

After the M56 booster burns out, the booster is separated from the payload. Once exo-atmospheric, the target shroud is deployed and pulled out of the ballistic trajectory path by a canted nose mounted motor. Shortly thereafter, the target is pneumatically separated and performs its cold gas thrust. Immediately after the cold gas thrust is complete, the target reorients 180° so the PMB can track the visible strobe located in the target nose.

Several events occur prior to application of projectile power. The canister is vented to space and opened. Helium and vacuum lines are severed. About six minutes after launch the projectile receives power and begins its automated initialization sequence. The Payload Module Bus performs an offset track during this time, keeping the target and other objects outside the LEAP field of view for more than 12 seconds while the projectile performs a nonuniformity compensation of the FPA against the cold space background. The Payload Module Bus then recenters the target in the field of view. The Payload Module Bus disables attitude control system thrusters while the LEAP averages rate gyro outputs. Values from the Payload Module Bus Inertial Measurement Unit (IMU) are input to the projectile to compensate the rate gyro bias errors. If the transfer of this data is unsuccessful, the LEAP will assume default values of zero degrees/second. This backup mode will ensure complete projectile performance demonstration, although the miss distance will be increased.

During the few seconds prior to LEAP ejection the cryogen supply from the PMB is stopped and the line is vented and severed. The projectile FPA cooling is then supplied from its onboard supply. The LEAP propulsion system is readied by venting manifolds to space vacuum and pressurizing the propellant tanks. The projectile thermal battery is activated and power from the Electrical Interface Unit is removed. The target solid boost motor burns out two seconds prior to LEAP acquisition to ensure a non-boosting target. After target motor burnout the PMB initializes the LEAP with target relative velocity and position vectors which have been transmitted from the target. Similarly to rate gyro initialization, if this data transfer is unsuccessful, the LEAP will default to values predicted for this trajectory. This backup mode will provide complete demonstration of projectile performance, though the miss distance will be increased. The Payload Module Bus begins a very small maneuver just as the LEAP begins acquisition of the target three seconds before ejection. The PMB motion ensures the subpixel target is not obscured by a dead cell in the FPA and prevents a bright cell from being mistaken as the target. The PMB stabilizes and disables attitude control thrusters 200 milliseconds prior to ejection to avoid excessive disturbances that could cause the LEAP to lose lock on the target during ejection. LEAP software algorithms enable reacquisition of the target shortly after ejection if loss of lock does occur, providing the target was acquired before ejection.

The LEAP is ejected when the target is 13 kilometers away. Retraction of the umbilical harness which interconnects the LEAP to the PMB (via the Electrical Interface Unit) removes the last physical barrier to ejection. Based on timing supplied by a discrete signal which changes state at umbilical separation, the LEAP enables its attitude control thrusters within 30 milliseconds after ejection. Attitude control is used to maintain track on the target while the projectile moves axially from the PMB at 30 centimeters/second (12 in./sec.) due to the ejection stroke. The projectile divert thrusters are enabled 1.5 seconds after ejection, providing 11 seconds to divert to intercept the oncoming target. The projectile closed loop guidance provides correction for up to 10 meters/second and 300 meters errors in the lateral target relative velocity and position components, respectively. Guidance continuously updates the sensed lateral target velocity until the target fills the projectile field of view at 80 meters distance (blind range). At this point, 10 milliseconds before intercept, the projectile guidance assumes the target velocity is maintained at the last calculated value. Three sigma predicted miss distance from the center of the target is less than 0.5 meter. This ensures very high probability of successful intercept, since the sum of half the diameters of the target and projectile is 0.6 meter.

IV. Post Launch Data Reduction to Evaluate Mission Success:

As the LEAP projectile diverts away from the Payload Module Bus (PMB), it transmits telemetry data to a receiving antenna on the PMB. The PMB retransmits this data to the ground receiving stations using a 10 Watt transmitter. The projectile contains a lightweight 0.5 Watt transmitter, so the PMB relay of LEAP data to the ground is the primary source of data. However, as a backup, the ground receiving station with the highest gain antenna will be used to collect data directly from the projectile transmission.

Telemetry data from the LEAP contains full performance verification and significant housekeeping parameters. Full field, 60 Hertz Infrared video data is included in the telemetry data. The entire projectile, including each of the critical technology developments described in Section II will be evaluated.

A health check is performed on the Electronics Unit large scale integration (LSI) components upon power up. Indications from this test are included in telemetry data. FPA and power regulator temperatures are also included in telemetry. Many of the software telemetry parameters (video content, clocks, mode flag, configuration flag, interrupts) also indicate health status of the Electronics Unit.

Video content is a performance indicator of both the optics and the FPA. Other parameters used to evaluate the Infrared Seeker include mean and standard deviation of noise, video threshold, target intensity, target size, dead cell count and signal to noise ratio.

Propulsion system performance is indicated by a wide array of telemetry signals. The most significant of these include helium and propellant tank pressures, thruster commands and resultant body rate and acceleration information, and center of mass estimate.

Tracking and guidance software algorithms are verified by various software telemetry outputs. These include target histograms and feature extractions, aimpoints, track gate position, Kalman filter outputs, compensated and uncompensated gyro and accelerometer readings, virtual miss estimate, relative target range and velocity calculations, target size and centroid, and target hits and track gate files.

Support subsystem performance is also validated by telemetry. The telemetry subsystem is verified by sync words and telemetry frame format accuracy. Inertial Sensor Assembly performance is indicated by rate gyro and accelerometer outputs and the noise levels on those signals. Battery performance is inferred from the functionality of the Electronics Unit and other subsystems. In addition to projectile telemetry data, many housekeeping parameters on the LEAP and its support Canister, Electrical Interface Unit and Cryogen Storage System are included in the PMB telemetry data. The PMB telemetry data includes voltages, currents, temperatures, pressures, squib currents, and LEAP projectile discrete outputs indicating timeline and status.

A simulation of the projectile hardware has been integrated with a software emulation to provide mission success predictions. A large portion of this model has already been validated using data from ground tests (Air Bearing, Strapdown and Hover). The LEAP 2 space test data will be input to the projectile simulations to validate the simulation model for space applications. Data used for this purpose includes initial conditions and any measured or derived hardware performance values. Examples of initial condition and performance data include actual target velocity and position data, target velocity and position data provided to initialize the projectile, measured gyro noise, derived thrust values, and measured ejection tipoffs.

V. Summary

The Army LEAP design has been thoroughly demonstrated by Air Bearing, Strapdown and Hover tests. The projectile to be used in the LEAP 2 space test has completed functional and acceptance testing at Hughes and will begin the process of integration with the Payload Module Bus in January of 1992. Analysis, testing and simulation/emulation give confidence that the LEAP 2 mission will succeed.